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Characterization of two novel low frequency microphones for photoacoustic gas sensors

Alessandro Sanginario[a], Christopher Grinde[b], Per Ohlckers[b]

[a] *Politecnico di Torino, Physics department, C.so Duca degli Abruzzi 24, Torino 10129, Italy*
[b] *Institute for Micro- and nano System Technologies, Vestfold University College, Borre, Norway*

Abstract

The photoacoustic principle for measuring gas concentration is well established based upon macromechanical assembly. However, microsystem based photoacoustic could benefit from smaller size and lower cost, but needs a high resolution microphone to be competitive. Here we present the characterization of two dedicated low frequency microphones. Both microphones have been fabricated in the same MPW foundry process, but additional post processing step enabling narrow ventilation slots through membranes of multiple thickness that increase the sensitivity of microphones, has been used. Preliminary results indicate a sensitivity of 800 µV/V-Pa, sufficient for high resolution photoacoustic gas sensors.

Keywords: MEMS, Photoacoustic Gas Sensor, Characterization, Microphone, MPW

1. Introduction

The use of gas sensors to detect the concentration level of a gaseous analyte (i.e., species of interest) using the photoacoustic effect is well known[1]. A photoacoustic gas sensor system (Figure 1) converts the optical energy of an amplitude modulated light source into acoustic energy when the light excites the gaseous analyte.

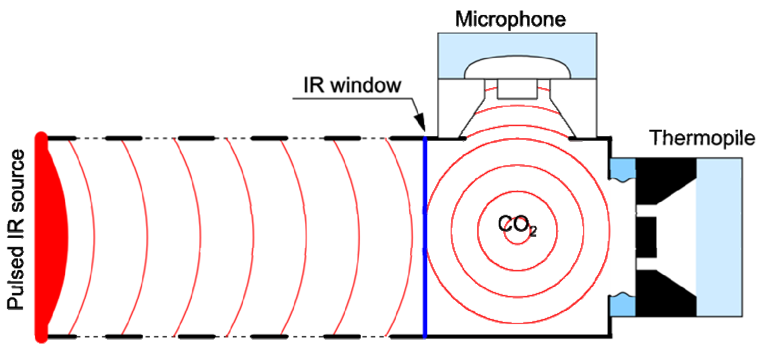

Fig. 1. Outline of the sensor system. A pulsed IR source emits IR light through a ventilated chamber. At the opposite end of the chamber sits a reference chamber. The intensity of the inbound IR light is proportional to the CO_2 concentration in the ventilated chamber. In the reference chamber, the light is absorbed as heat, which in turn leads to thermal expansion and pressure increase of the gas. The thermal expansion leads to an acoustic signal, whose amplitude is inversely proportional to the CO_2 concentration in the absorption path. The acoustic signals amplitude, and hence CO_2 concentration can be monitored using a microphone.

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The optical energy of the light incident on the sensing chamber is, upon absorption by the analyte gas, converted into heat causing thermal expansion whose amplitude is proportional to the inbound IR intensity. Their amplitude can be measured with a microphone whose amplitude will be inversely proportional to the gas concentration. When using a solid state IR emitter, these devices operate in the frequency range of 20 Hz –100 Hz[2]. One of the main challenges when miniaturizing a photo acoustic gas sensor with a solid state IR emitter, is that due to a upper operating frequency of 100 Hz[2], acoustic resonance can not be used for signal amplification and hence a very sensitive microphone is required. Microphones designed for this application has previously been reported with sensitivities of 11 micro V/V-Pa[3] which is not sufficient for the application. For this reason two microphones, having high sensitivity at low frequencies, have been fabricated. Here we present their characterization.

2. Materials and methods

2.1. Microphones

To increase sensitivity, the microphones presented here, are made with membranes with perforations along their edges and suspended by four beams, centered at each of the sides. To maximize the surface area, while fitting the sensor inside the predefined die sizes from the MPW service[4] used, the beams are embedded inside the membrane area. The resulting geometry resembles a four leaf clover with beams attached between its leafs. Two version of this concept has been fabricated using the multi project wafer (MPW) foundry service MultiMEMS[4], one comprising a thin (3.1 µm) perforated circular membrane suspended by four beams, as illustrated in Fig. 2(a) and one with a thick (23.1 µm) square membrane as illustrated in Fig. 2(b). The thin membrane design uses the standard MPW foundry process, while the thick membrane design use an additional process offered by microBUILDER[5]. Further details on the design can be found in[6]

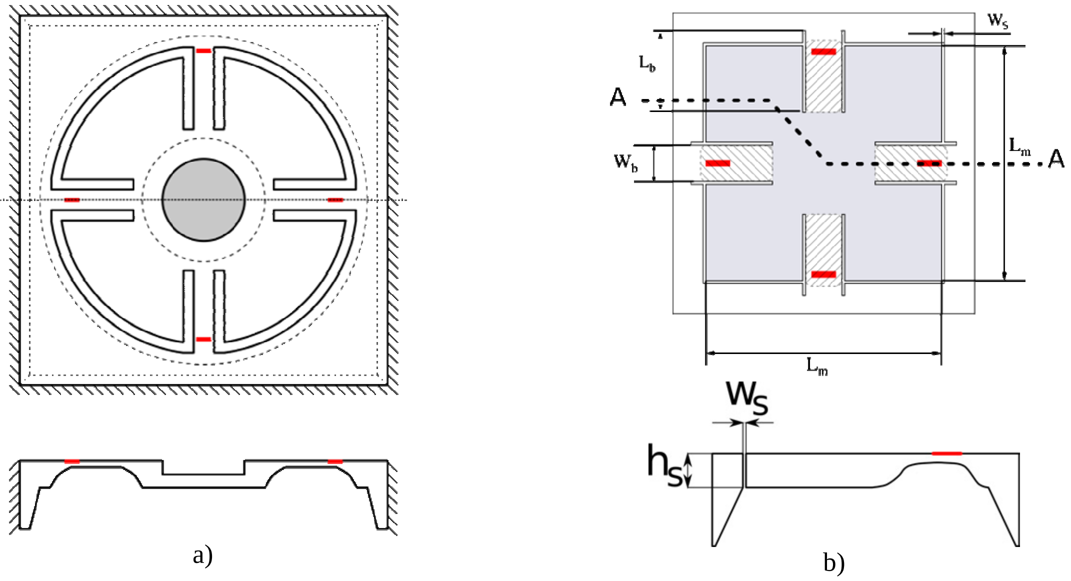

Fig. 2. Two versions of the design concept has been fabricated, one with a thin (3.1 µm) circular membrane area(a) and one with a thick (23.1 µm) square membrane(b). For both versions, the membrane area is suspended by four thin (3.1 µm) beams, that start and end in thick regions. For the circular design, a 10 µm deep recess is included in the center of the central boss.

2.2. Characterization setup

Fig. 3 shows the characterization setup: everything is controlled by a Labview software which controls a National Instruments DAQ card (USB-6211). The software generate a sinusoidal signal at desired frequency and amplitude which leads four parallel connected loudspeakers; as the NI card can not provide enough current to drive the loudspeakers, a power amplifier with unity gain has been used to provide the necessary power. Loudspeakers are positioned at four of the sides of the cubic acoustic chamber shown in Fig. 4. The Labview software developed consists in two main parts, the generation and the acquisition. A simple GUI has been implemented with fields for frequency range and frequency stepping. Sinusoidal waves with a 80 kHz sample rate is generated and sent to the loudspeakers.

The acquisition block collects data from both the reference microphone and the microphone being characterized as well as the supply voltage. For each frequency, peak to peak amplitude is averages over a selectable number of cycles to improve the SNR. All data collected are logged to file for further processing with the open source numerical computing environment Octave[7] and then displayed according our needs.

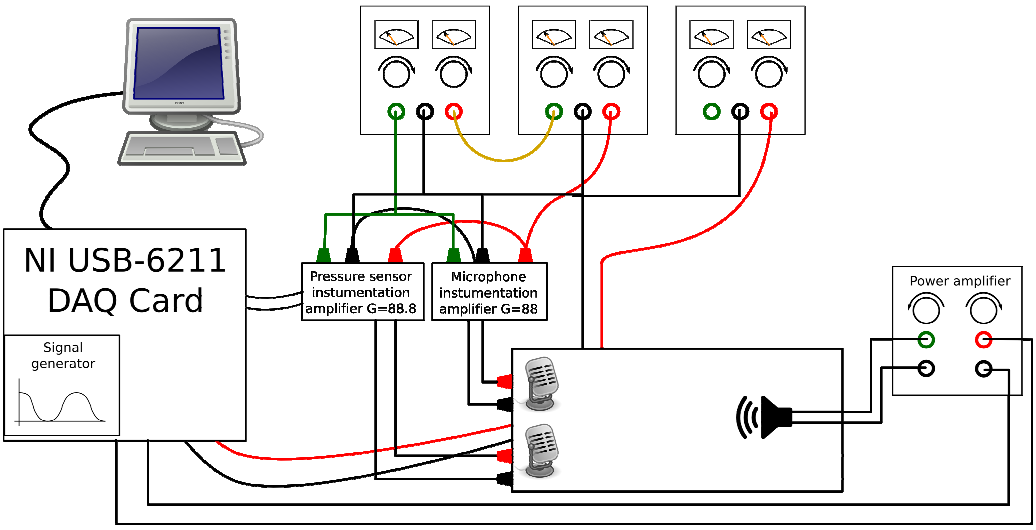

Fig. 3 Characterization setup: a NI DAQ card, controlled by a pc, generates sinuses at different frequencies and amplitudes to control loudspeakers. Both the microphone and the pressure sensor outputs are amplified by two instrumentation amplifiers and then recorded by the NI card.

3. Results and discussion

Figure 5 shows preliminary results for two different power levels. The results shown are not normalized to compensate for the loudspeakers frequency response. The lower peak is within the range of the resonance frequency of the loudspeaker elements (270 Hz ±20%) and further development of the setup is needed to compensate for this and the lack of sound pressure at frequencies below 200 Hz. For frequencies above 1000 Hz the microphone response is flat and at a sensitivity of 800 μV/V-Pa which is about 80 times the sensitivity of a similar, non perforated membrane design[3].

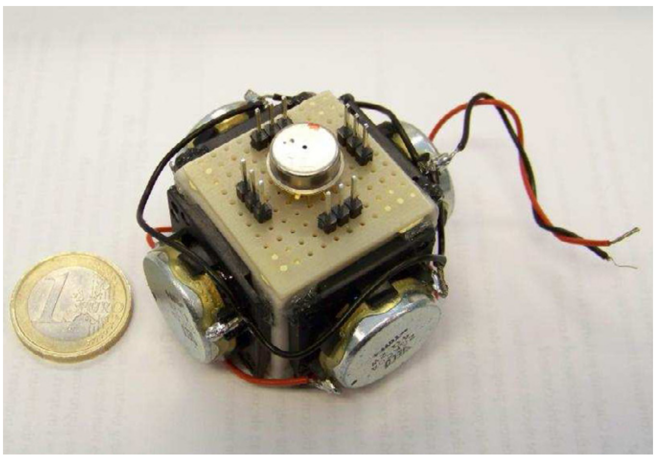

Fig. 4 An hollow cubic structure is the skeleton to hold loudspeakers, reference pressure sensor (not present in the picture) and the microphone to be tested. All loudspeakers are connected in parallel and the holes of the PCB are closed with a veil of soldering tin in order to lose as less sound pressure as possible.

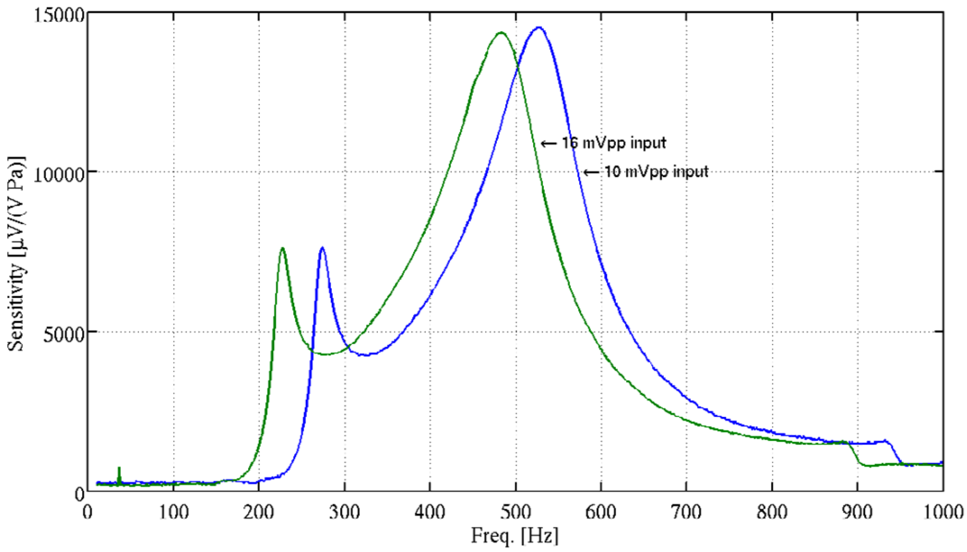

Fig. 5 Preliminary results: two sinusoidal waveforms of different amplitude was used as input for the generation of the sound. Note the left shift on increasing input power. The plot shows collected data with no normalisation to the loudspeaker frequency response. The flat section to the very left gives the reported sensitivity.

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